the government immediately specify and transfer 50 MHz to be allocated for unlicensed private wireless telecommunication services and has invited comment on who should be able to use it.[17]

4.5 Mass market demand and supply

When considering the market efficiency or desirability of various technologies for the NII, it does not really matter what the *ex-ante* market supply conditions are if *ex-post* market acceptance never materializes. Successful market entry will hinge on issues of service choice, quality, convenience and low prices. The market cannot be ignored when developing government technology and competition policy. Successful market entry into the wireless access business will require that a system feature portability, that it is interconnected to those not on the local system, and that its (quality adjusted) price is affordable.

The costs of making a call on wireless networks is, and will, for some time to come, continue to be more expensive than wireline network calling, partly because it actually costs more to provide the service and partly because there is a willingness to pay a premium for the convenience of portability. The clearest evidence of this for the mass market is the explosive growth of cordless telephone units in spite of their relatively high price - on average about four times that for a wired telephone. The cost of usage is the same for both, so this is a good metric for evaluating the value to consumers of portability, at least for fixed-base-station service.

While it may cost only a dollar to make a cellular phone call from a car, that same call from a remote location or a cruise ship can easily cost ten times that. Of course, part of the reason is the lack of alternatives in captive markets, just like pricing food services in a ballpark, but part is also due to underlying costs of providing the service. Communicating while "on the move" has always cost more than standing still. Calling long distance has always cost more than calling locally, and so on. Even when considering using a satellite service, which, due to the nature of the technology tends to be distance insensitive, there are still significant issues of the technology and cost of transporting the call to the exact location of the called party, who may be on the move.

It is obvious that consumers accessing the NII would like their portable phones to work in all three portability modes providing a full range of services. But not if the price is too high. There is always the option of having two or three different phones and putting up with the hassle of having to remember to always have the right phone in the right place. Many Americans already have a cordless and cellular phone in addition to their normal wireline service and inexpensive pagers are now rapidly being added to the mix.

Nevertheless, there is a huge debate raging among experts on the demand side of the wireless future as to whether or not people will continue to buy so many different phones and at what price, even if each one is relatively cheap compared to a triple-mode phone. Indeed, as cellular phone operators have discovered, the price which consumers face for handsets, as well as the cost of making a call, is an important determinant of mass market demand. Regardless of one's conviction that many consumers will pay a premium to avoid the hassle of owning more than one phone for each mode of operation, the mass market will remain very price sensitive. Therefore, to assure a high level of residential demand and mass market penetration the incremental cost to consumers for handsets featuring multi-mode operation had better be somewhere close to the total cost of owning different handsets. Consumers today seem to be able to put up with the hassle of owning a separate pager, cell phone, and *cordless telephone* (CT) unit without too much complaint.

Residential local phone calls are provided "free" almost everywhere in the U.S.. Only a few states charge for local PSTN calls and even then the charge is quite low at 1-2 cents per minute. This means that whatever the costs of providing for local phone calls, the telephone companies recover it from the monthly charges on other services, especially business phone lines, or from long distance services. This fact makes it very difficult, if not impossible, for independent wireless network operators to enter and compete in the mass market for local telephony because it is hard to compete against a zero price for usage when there is no source for subsidizing such entry (e.g., toll calling revenues). This sets the mass market entry price "bogey" for wireless companies to be in the range of monthly charges that incumbent wireline telephone companies charge for local service, which currently runs about $18 per month per household nationwide.

This also helps to explain why interconnecting carriers, especially long distance companies interested in becoming the beneficiary of their own payments to local telcos, are at the forefront of those clamoring to get into the wireless access business. For example, AT&T's takeover of McCaw cellular allows for the possibility that McCaw customers will be saving on payment of subsidies associated with their calls using AT&T, which, in turn, saves by reducing the amount it must pay out to the local telephone companies for access to the PSTN.

Cable television companies are the next most logical entrant into the market for local telephony as they see their use of wireless access as a two-way voice and data channel which allows them potentially to become a full service multi-media communications provider. Cable companies and other independent wireless network operators however, face the dâunting prospect of paying high prices for interconnection to the telco's PSTN facilities to guarantee nationwide service capability to their subscribers. No wireless access system can become a viable market player unless ubiquitous call terminations anywhere in the country can be achieved. Current local telco interconnection charges are very high at an average $.07 per minute. This is so high as to be the single highest non-network operating expense of potential wireless access service providers.[18]

The FCC has often stated that it believes that wireless access services are the best hope for introducing competition into local telephone service markets. If this is to be the case, then Federal and State regulators need to level the playing field of market entry by reducing toll and interconnection charges and business service cross subsidies by deregulating the local and toll charges of incumbent wireline carriers.[19] If this is not possible, then the Administration and the FCC had better plan on seeing some very familiar faces on the wireless scene as incumbent suppliers jockey for position to bypass one another (or even themselves) using the new wireless network alternatives to save on paying cross subsidies.

Unfortunately, the new telecommunications law is not very much help in this regard. While the new law does contain suggestions for reforming PSTN access charges, it also recommends that all service providers interconnecting to the PSTN (which, by definition, includes new wireless network operators) share in the burden of cross subsidizing the ongoing costs of funding the universal availability of advanced wired networks. In years past, this cost burden was largely borne by long distance service providers in the form of PSTN access charges. Now it may be applied to wireless operators as well. This would be sure to substantially increase the costs of interconnection for wireless network operators. On a more positive note, the new telecommunications law does eliminate requirements for *commercial mobile radio service* (CMRS) providers, which encompasses all cellular carriers, to provide so-called Òequal accessÓ to their systems. This allows for cellular carriers to join together in exclusive dealing and interconnnection arrangements with long distance service providers or others, increasing the opportunities for cellular carriers to bypass the networks and local access charges of traditional local exchange carriers. However, for terminating cellular calls to wired public network subscribers, it will always be difficult to bypass the high access charges of local telephone companies.

For now and the foreseeable future, local telephone companies cross subsidize a portion of the costs of providing basic local exchange service from profits on business services and access charges paid by interconnecting toll carriers. This artificially raises the price of interconnection to the public telephone network for toll carriers and lowers it for the interconnected local networks. Eliminating all or a portion of the artificial cost burden this places on interconnecting toll carriers, and, in turn, the cost benefit it confers on local telephone companies, will cause interconnection charges among local telephone companies to rise and this will dramatically reduce barriers to entry in markets for local access and transport services.

While it is entirely possible that, under deregulation, the same telephone companies and cable television companies would eventually dominate the new wireless markets anyway, it would be preferred for the FCC to allow entry on an equal footing to new entrants if, as the FCC has stated more than once, its new wireless policy is to "let a thousand flowers bloom."

4.6 Cost structure of wireless communications

The conceptual model of a wireless access network system is simple. Just like all radio communication systems, wireless access is fundamentally a "line of sight" technology. The basic characteristics of wireless network systems are illustrated in the stylized network in figure 4.1. This simple generic system includes the essential aspects of all digital land-based systems now being considered for the NII, some of which are up and running in actual test market applications and most of which are still in the prototype testing or development phase.

Figure 4.1 Basic characteristics of wireless access system.

Wireless access systems in the NII will be "open" networks allowing for public access on demand for both call originations and terminations (assuming system capacity and spectrum utilization is engineered to meet demand in a given market area). This is not to say that the handsets or other consumer terminal devices which are required to access the wireless network are themselves "open." While most wireless access system network operators in the NII will need to conform to generic *network network interface* (NNI) requirements, this is not necessarily the case for the *user network interface* (UNI) connecting user terminals to the network. Many local wireless network operators, especially very large ones, may use proprietary signaling protocols for transmissions between handsets and base stations depending on the particular choice of technology and network control software.

In figure 4.1, a base station tower is connected to a subscriber's handset for two-way digital transmission. This connection may or may not pass through other network node points between the tower location and the handset depending on the type of wireless access system. Each base station is potentially also connected to another base station tower in the network or through a network switching center which is itself connected to the PSTN so that calls from the subscriber handset can terminate anywhere. The Mobile Switching Center or MSC is a primary network node which represents the control point of the wireless access system. The MSC is the "brains" of the network and performs complex network operation and control functions, including, in cellular systems, call hand-off. For roaming functions and other future intelligent network functions (e.g., call waiting, three way calling), the MSC communicates via a packet data link with a *home location register* (HLR--not shown in figure 4.1). The HLR is a computerized database which keeps track of the locations of mobile units and performs other functions yet to be determined.

The counterpart of the MSC in analog systems is the *mobile telephone switching office* (MTSO) which serves as the network host node for existing mobile cellular systems in North America (*advanced mobile phone service* (AMPS)). In a network system, the

MSC node will be interconnected, usually by high-capacity wireline or point-to-point microwave radio trunks, to the PSTN. In certain types of single coverage area wireless access systems (e.g., SMR), the MSC node location may also serve as a *base station* (BS) connected via RF links directly to subscriber handsets. In cellular network systems, the MSC serves as a digital host network controller connected via microwave or fiber optic links to one or more BSs, also called *base station systems* (BSSs). Figure 4.2 illustrates a BSS. A *base station controller* (BSC) is the host node of a BSS. The BSC performs basic network functions such as channel allocation, link supervision, transmitted power level control and transmission of network signaling information. The BSC serves remote nodes called *base transceiver stations* (BTS). In cellular systems, the BSC could be connected to BTSs via either wireline or wireless trunk connections.

Figure 4.2 Base station.

Conceptually, newer land-based wireless access systems are no different from the way an old-fashioned Mobile Telephone System (MTS) works. But this is where the similarities end. The poor signal quality, lack of privacy, small coverage area, short distance and congestion typical of old analog two-way radio systems would never have developed into full mass market penetration because nearly every household already has ready access to a regular phone line to obtain high quality telephone service.

To overcome the list of problems with traditional analog two-way radio services, digital wireless access systems are immensely more complex. Through the use of sophisticated microelectronics, digital wireless access systems are potentially able to meet or even exceed current wireline network quality and reliability for voice and data services. There are now several wireless network systems contending for prominence in the NII featuring unique network design characteristics and cost structures.

4.7 Wireless access network characteristics and costs

This section describes the basic network design for the four types of digital wireless access systems described briefly in the first section: a. cellular, b. non-cellular, c. wireless cable and, d. satellite.

4.7.1 Cellular

This category of digital wireless access systems includes all types of cellular configurations regardless of the size of the individual radio cell (macrocell, microcell, picocell, etc.). For purposes of discussion, digital *cordless telephone* (CT) technology will also be discussed even if it does not conform to the cellular radio model because it is likely to be used in conjunction with some cellular systems. The basic wireless access network described in figure 4.1 and discussed earlier featured all of the basic building blocks of digital cellular networks. The primary distinction between different cellular network configurations is the size and structure of the cells and, in turn, corresponding differences in system signaling, handset power levels, channelization schemes, co-channel interference and reuse factors.

Digital AMPS (AMPS-D)

Digital signal processing techniques will ultimately allow for substantial capacity gains over AMPS. In the US, the purpose of first generation digital cellular systems is primarily for upgrading analog AMPS systems to expand network capacity. This is not true in other developed countries where digital cellular systems are separate from older analog mobile systems, or in less developed countries where analog systems were never deployed.

AMPS utilizes *frequency division multiple access* (FDMA) techniques and AMPS-D systems use the more efficient *time division multiple access* (TDMA) techniques. To allow for a smooth migration of subscribers from old to new technology AMPS-D systems are designed to operate in "dual mode" with current AMPS systems (i.e., using a portion of the same 25 MHz spectrum licensed to AMPS operators). Now that the FCC has allocated an additional 120 MHz of radio spectrum to PCS there will soon be new TDMA network operators on the scene.

Just as in the application of time division multiplexing in the PSTN, digital radio TDMA techniques allow AMPS operators to expand capacity by sharing the same communication channel among users. Digitally enhanced versions of AMPS (e.g., Narrowband AMPS or NAMPS) provide an effective short term method of expanding the capacity of AMPS cellular systems and provide a bridge to deployment of fully digital systems.[20] Under the IS-54 North American TDMA standard, NAMPS uses the same bandwidth per carrier channel as AMPS (30 kHz), but by allowing three users to share it, the bandwidth per voice channel is only 10 kHz (20 kHz duplex) instead of the full 30 kHz (60 kHz duplex), for a three to one capacity gain

Tables 4.1, 4.2, and 4.3, taken from Uddenfeldt (1991), are valuable for gaining a basic understanding of some distinguishing characteristics of leading alternative digital cellular systems. Table 4.1 provides a comparison of digital cellular standards for European, American, and Japanese systems. Table 4.2 compares them to the capacity of current North American AMPS systems. Table4.3 provides the basic distinguishing characteristics of macrocell, microcell, and picocell systems.

Table 4.1
Comparison of digital cellular standards for European, American and Japanese systems

	GSM	ADC	JDC

Access method	TDMA	TDMA	TDMA
Carrier spacing	200 kHz	30 kHz	25 kHz
Users per carrier	8 (16)	3	3
Voice bit rate	13 kb/s (6.5 kb/s)	8 kb/s	8 kb/s
Total bit rate	270 kb/s	48 kb/s	42 kb/s
Diversity methods	- Interleaving - Frequency hopping	- Interleaving	- Interleaving - Antenna diversity
Bandwidth per voice channel	25 kHz (12.5 kHz)	10 kHz	8.3 kHz
Required C/I	9 dB	16 dB	13 dB

Notes: GSM - European Standard
ADC - North American Standard
JDC - Japanese Standard

Table 4.2
Comparison of capacities of European, American, Japanese and current North American AMPS systems

	Analog	GSM		ADC	JCD
	AMPS (ref)	Full rate	Half rate		
Total bandwidth (B_t) in Mhz	25	25	25	25	25
Bandwidth per voice					

channel (B_c) in kHz	30	25	12.5	10	8.33
Number of voice channels (B_t/B_c)	833	1000	2000	2500	3000
Re-use factor (N)	7	3	3	7	4
Voice channels per site (M)	119	333	666	357	750
Erlang per sq. km (3 km site - site distance)	12	40	84	41	91
Capacity gain	1.0(ref)	3.4	7.1	3.5	7.6

Table4.3
Basic distinguishing characteristics of macrocell, microcell, and picocell systems

	Macrocells	Microcells	Picocells
Bandwidth allocation	11.34 MHz (11134 channels)	1.26 MHz (126 channels)	1.26 MHz (126 channels)
Channel allocation	Fixed	Adaptive	Adaptive
Transmit peak power per voice channel	6 Watt	0.6 Watt	0.03 Watt
Antenna configuration per site	120^0 sector	Omni	Omni
Erlangs per site	148	6	2
Site - site distance	3 km (hexagonal)	0.3 km (rectangular)	0.06 km (rectangular)
Erlang per sp. km and Mhz	1.6	52	2300/floor

Erlang per sq. km	18.2	66	3000/floor

In the current macrocell environment, the capacity of a cellular system is normally determined by calculating the number of simultaneous users M per base station cell site for a given amount of RF spectrum, B(t). The system capacity therefore is: M=1/N [B(t)/B(c)], where B(c) is the equivalent bandwidth of a voice channel and N is the RF reuse factor. Table 4.2 shows that current generation digital cellular systems using TDMA offer 3-8 times the capacity of AMPS systems without adding new cell sites or resorting to microcell deployment. AMPS-D is at the low end of the range.

Lee (1993) has also estimated the capacity gains when comparing new digital cellular systems with AMPS. Using a fixed amount of spectrum for a radio carrier channel (1.25 MHz), AMPS FDMA systems feature a capacity of 6 radio channels per cell, while TDMA features a capacity of 31 channels (5 x FDMA). Code Division Multiple Access (CDMA) techniques, which are relatively new in commercial applications, offer system capacities of 120 channels (20 x FDMA).[21]

The per subscriber capital costs of current AMPS systems is about \$700-\$1000.[22] The per subscriber capital costs of AMPS-D systems (TDMA) is much lower at about \$300-\$500.[23]

Global System for Mobile communications (GSM)
The earliest and most prevalent global standard for digital cellular service is the European GSM (TDMA) standard. GSM, like North American cellular radio telephone systems, operate in two distinct frequency bands which the government has allocated to cellular mobile (900 MHz) and PCS services (1800 Mhz GSM and 1900 Mhz U.S.). For obvious reasons, it is important that these two systems may interwork with one another and GSM has proven that they can. Many GSM systems are already operating or are in the deployment phase throughout the world. The newer version 1800 Mhz GSM systems are called DCS 1800.

GSM TDMA techniques can achieve considerable capacity gains over AMPS (about 7 to 1, see table 4.2). While the US has already adopted the interim IS-54 (TDMA) standard for AMPS-D, it is still possible for new US wireless access network operators, or incumbents for that matter, to adopt GSM techniques.[24] Indeed, large GSM system equipment vendors (e.g., Ericsson) will be targeting U.S. markets to compete with North American standards. In allocating cellular spectrum for PCS, the FCC has left wide open the choice of wireless access scheme. Carrier channels in GSM have considerably more bandwidth than those in AMPS-D, and therefore may handle more voice channels per carrier. But, the real advantage of GSMÕs wider carrier channel bandwidth (200 Khz) may be the migration from supporting voice to multimedia and high speed data services. The per subscriber costs of GSM systems are in the range of those found for AMPS-D.

To expand the capacity of digital macrocell networks like AMPS-D and GSM, antenna diversity and cell sectorization techniques may be employed. For example, the transceivers and associated omnidirectional antennae at BTS cell sites may be reconfigured by employing directional antennae to split the cell into sectors, like slices of a pie. In addition, altering the power output to distinguish handsets according to near/far conditions is another technique which may be used to gain capacity within the cell area. In this case, the cell is split into concentric zones based on distance from the antenna location, rather than like slices of a pie.[25] It is also possible for cellular system operators to adjust cell sizes and cell coverage areas using combinations of directional antennas and powering schemes.[26]

Increasing capacity to handle increased demand in wireless access systems often simply involves the placement of more transceivers on an existing BTS tower. For example, assume that service begins by placing a single omnidirectional antenna on a tower serving a single carrier radio channel. In a GSM system, a single radio channel is time multiplexed into 8 virtual channels, 7 of which may be accessed by subscribers, and one of which is reserved for network functions. To increase capacity, a BTS cell may be split into three sectors by placing additional transceivers on the tower and employing directional antennae, each serving one carrier channel, like a pie sliced into thirds; this situation may be characterized as a 1x1x1 antenna configuration (i.e., one antenna facing each direction). When capacity at that BTS site needs to be expanded further, additional directional antennae may be placed on the same tower and may be added for the particular cell sector needing capacity relief (e.g., 1x2x1, 2x2x1, etc., up to a 3x3x3), or when there are no more carrier channels available.

There are other methods of increasing system capacity while holding constant the available RF spectrum. Digital signal processing techniques may be used for adaptive channel allocation and lowering the bit rate for digital voice coding.[27] Incremental changes in per subscriber or per minute system costs associated with the adoption of these types of innovations in voice coding are not yet available.

GSM Evolution

By now, GSM systems have moved beyond their initial Phase of deployment in order to add new functionality and services. As new system capacity constraints were experienced and in order to save on system expansion costs, GSM systems turned to half rate (8 Kb) voice coding schemes to achieva a nominal 2 to 1 gain in the number of subscribers the system can support. This decision however involves a trade off in voice quality, esecially when calls are made between two cellular subscribers, each with half rate digital voice coding. This is also problematic if GSM is to evolve toward a universal wireless service for the mass market and as a potential substitute (or at least not too inferior complement) for fixed wired telephone service operating with voice channels of 64Kb/s each (even though high quality voice does not require that much bandwidth) and with digital cordless systems offering 32 Kb voice channels. New GSM *enhanced full rate* (EFR) voice coders operating at about 13 Kb increase voice quality and still fit within the 16 Kb full rate GSM voice channel. This EFR coder may also be used in the U.S.Õs 1900 Mhz systems.

Other new GSM network services on the horizon include conferencing and related group calling services, enhanced and intelligent network services such as call forwarding and call blocking, packet data and even high speed data services.[28] Compared to fixed wired networks, the use of enhanced and intelligent network services features and functions in cellular radio networks presents some very special problems for the core network system which always has the difficult task of keeping track of where subscribers are located to preserve the integrity of individual messages and connections across cells or even neighboring systems. This would call for substantial expansion of the functionality of the HLR which may be viewed as the future wireless counterpart of the *network control point* (NCP) component of the traditional *intelligent network* (IN) used used to provide network routing and number translations for the public telephone network.[29] GSM network designers are also considering ways to allow GSM and advanced digital cordless systems like DECT to work together. Similarly, an effective interface to allow interworking between GSM systems and new digital global satellite systems is being investigated.

One very attractive future GSM system development involves globalization. As more and more countries adopt the technology, extended inter-country roaming becomes possible. A standardized *subscriber identity module* (SIM), an electronic card which would plug in to a cellular handset, could provide the necessary functions required for system compatability, fraud protection, and billing accuracy across totally different cellular systems.

Macrocell mobile systems and PCS

The beauty of cell sectoring in celluar radio systems is that, using essentially the same type of network equipment, the cost of increasing individual cell capacity may grow incrementally over time as demand grows. Even in a microcell environment, it is possible to employ cell sectoring schemes to increase capacity and transmission quality.

The use of cell sectorization techniques in a macrocell environment to improve RF reuse in a given market area has the same effect, but at less cost, as implementing microcells. By "piggybacking" early PCS service demand on the macrocell network, mobile system operators believe that they can compete against the capacity and performance of new microcell wireless access systems. In fact, this has been the pronouncement of most major cellular operators in the US, who contend that they have a significant head start and market advantage over new microcell PCS operators. Some of these pronouncements are suspect, because the FCC has restricted incumbent cellular network operators to acquiring a total of 15 MHz of PCS spectrum per market area.[30] This places incumbents at a competitive disadvantage to other new PCS operators which are allowed a total of 120 MHz (40 MHz each) per market area. Thus, it behooves existing operators to announce early-on their intention to compete in the PCS market in order to gain customers and to signal new entrants of their intentions to compete using their existing cellular system and RF endowments.

Once the demand for PCS grows to the capacity limitations in the sectored macrocell environment, the mobile network operator still has the opportunity to split the coverage area into smaller cells. This further expands system capacity and begins to mimic the network design of the microcell system operator. This should give microcell network operators pause if they believe that their choice of technology is somehow unique in serving the market for PCS. In fact, recent research suggests that both TDMA and CDMA may be cost effectively applied in a macrocell environment until such time as capacity constraints require adopting a microcell system structure.[31]

Other things equal (e.g., system demand), it is always more expensive to deploy microcells than macrocell systems because this means incurring more radio tower sites and associated transceiver equipment costs. Microcell systems require the placement of many more nodes (BTSs) per coverage area, and, to the extent that such placements may be delayed by macrocell network system operators without sacrificing tapping into the early PCS market potential, it behooves mobile network operators to squeeze as much capacity out of their macrocell network as possible. If PCS service demand were to skyrocket however, mobile operators will have to worry about system capacity shortages.

CDMA

CDMA macrocell cellular systems may use essentially the same architecture as that for TDMA, AMPS-D, and GSM systems. The primary difference is the considerable gain in system capacity by reducing the spectrum reuse factor from 7 to 1. The gain in spectrum efficiency (i.e., system capacity) for a given radio coverage area and fixed amount of radio spectrum is inversely related to the numerical value of the spectrum reuse factor. In CDMA "spread spectrum" systems, the bandwidth of the radio carrier channel is much greater and is shared among many more subscribers in the same cell. Cell sectoring techniques are also used to expand capacity in CDMA systems.

CDMA macrocell systems are not yet deployed and there are a number of possibilities for channelization schemes. Qualcomm, a major supplier of CDMA systems, has proposed a 1.25 MHz carrier channel bandwidth which can accommodate 25 voice channels. With cell sectoring (3 sectors per BTS) CDMA carrier channels have a capacity of 75 voice channels. For urban CDMA systems employing this sectored cell network configuration with over 50,000 subscribers, McGarty reports a per subscriber capital cost of about $350.[32] The per subscriber costs for urban systems are sensitive to subscriber density within a cell and the size of the coverage area. Holding constant the total radio coverage area, the per subscriber system costs increase rapidly for subscriber levels below 50,000 and could easily be 2 to 3 times the $350 number for very low penetration (e.g., 10,000 subscribers). The per subscriber costs slowly decrease as demand expands beyond 50,000 subscribers but flattens out very quickly. The same would be expected to be true for TDMA and even AMPS-D cellular systems.

PCS microcell

Microcell TDMA and CDMA wireless access systems use fundamentally similar radio technology compared to their macrocell counterparts, but with reduced cell sizes (e.g., 3 km radius, vs. .3 km radius). Reed (1992) studied microcell PCS network costs and reported the per subscriber capital cost to be about $500 for both TDMA and CDMA systems.[33] Interestingly McGarty (1994) reports fairly similar per subscriber costs (considering the rough level of the analysis) for large urban macrocell systems using either CDMA ($373) and TDMA (GSM) ($453).[34] As mentioned previously, these per subscriber system cost estimates are derived from static calculations of total construction costs, including start-up, divided by a target level of subscribers (e.g., 50,000). Using a different approach, once the initial system is built and operational, the estimated incremental capacity cost per minute for growth in network usage multiplied times the average system usage per subscriber (180 minutes per month), yields a TDMA per subscriber cost of about $200.[35]

In a mobile environment assuming fast hand-off capability, the implication from the available data is that microcell network structures have no inherent unit cost advantages over macrocell ones and that a network operator should delay the conversion from macrocells to microcells until capacity constraints require it. However, this reactive mode of operations could backfire if the early microcell system operator is better positioned to fill (unanticipated) PCS demand. It is also possible that if, in the near future, it is perceived by the macrocell system operator that capacity constraints in the macrocell system will create the need to reduce cell sizes, then squeezing as much capacity out of a macrocell system design before converting to microcells to relieve capacity may actually end up raising the total long run cost of operations. This would be especially so if the costs incurred for macrocell system capacity expansion were non-recoverable before being forced to eventually convert to microcells to improve capacity to levels required by rising demand.

Expense factors in cellular networks

There exists a wide range of estimates of marketing and operating expenses associated with new digital cellular wireless access systems.[36] Since the fundamental operations among competing carriers for stand-alone cellular systems are homogeneous (e.g., system administration, service provisioning, repair and maintenance, etc.), the on-going expenses for network operations are likely to be similar, or at least this is a reasonable assumption. Since competing carriers operate in the same markets to attract the same customers, marketing expenses could also be expected to be similar across carriers in the same market area. In the case of incumbent cellular carriers, especially vertically integrated ones, there may be some economies of scale and scope from reduced interconnection, operating and marketing costs. However, there is little to be gained at this early stage in comparing expense estimates since it is not likely to be the determining factor *ex-ante* in selecting one type of network system over another.

Cordless Telephone (CT) technology

ÒMobile multimediaÓ is the ultimate concept in digital cordless technology. The international vision of this concept has been called *universal mobile telecommunications system* (UMTS) and in the U. S. it is referred to as *future public land mobile telecommunication system* (FPLMTS). In 1992, the *World Administrative Radio Conference* (WARC) assigned 230 Mhz of spectrum around the 2000 Mhz radio frequency band to UMTS. It reamins to be seen if this is enough bandwidth to ever support a true mass market wireless multimedia network infrastructure. It is likely not and more bandwidth in higher frequency bands will likelyt be needed.

The goal of UMTS is to provide high quality high speed servvices with unlimited mobility and global coverage. Needless to say, achieving this concept will take a lot of work in the research and development community and there will no doubt be some serious setbacks. But, it is a valuable goal from a social infrastructure perspective and a useful vision to keep in mind for guiding wireless technology developments. UMTS is based on a *personal telephone number* (PTN). A PTN is like a PIN number that will be able to follow an individual wherever they go and whatever terminal they are use. International standards bodies are investigating how to keep track of incoming and outgoing calls in this new environment so that network and equipment standards may be developed. The reason that cordless telephone service, which is normally associated with a very limited and fixed coverage area, may be the key to starting to design a cost effective global mobile system is that most people most of the time are in fact close to home or their workplace. Recent polls in the U.S., known to be one of the most, if not the most, mobile society in the world, indicate that 90 percent of the time that individuals are out of their office are either within the same building or nearby. In order to achieve global coverage, UMTS may be interconnected with emerging global digital satellite networks. Many proposals to launch satellite personal comunication networks exist and these may represent the forerunner of the satellite portion of the global UMTS system.[37]

Compared to cellular service, CT technology generally features very low power, slow (or no) hand-off, and a limited base station coverage area. For very short distances from a base station unit, CT handsets may handle the network control functions which, in cellular roaming modes, would have been handled within the network. For example, a CT handset should be capable of automatic selection of an open channel from those available at the base station, the way some cordless phones already do today.

For obvious reasons, most telephone usage occurs while at home or in an otherwise stationary situation (e.g., office, shopping mall). This simple fact of life is what allows CT technology, which costs a lot less than a stand-alone cellular system, to become a potential market winner. The market for digital cordless phones in 1994 alone was $1B and doubled in 1995 to $2B and it is estimated to grow to $32B by the year 2000.

The network and handset costs associated with fast hand-off and roaming features offered in a mobile environment are very high compared to CT systems offering only fixed location or slow hand-off capability. However, such supply-side cost advantages may mean very little in terms of market success if consumers truly desire, and are willing to pay for, the added convenience of total portability in a mobile environment.

The US has no significant players planning to deploy CT technology except in conjunction with other plans for wireless infrastructure. CT's role in the NII will be as a complementary service offered in conjunction with, or interconnected to, other wireless networks; or as a cheap substitute for more expensive wireless network systems for those consumers that either do not want, or cannot afford, such access. Thus, CT network systems will not be examined herein except for their role in conjunction with other modes for wireless communications.

It is not that there will not be a demand for this service. Indeed the explosion in the demand for cordless handsets in American households makes that a given. In fact, we should be anticipating the day when infrared light is used in addition to, or as a substitute for, current CT radio frequencies in the home; using photonic phone technology, the numerous remote control devices for televisions and stereos could double as portable phones, pagers, and intercoms - as the futurists have put it, "We'll be watching our phones and answering the TV".

Around the globe, CT technology is beginning to be deployed in various forms, notably the UK, Japan, and soon in Canada. Compared to these countries, there is much less excitement and anticipation in the US regarding the deployment of advanced public CT networks among consumers or major players in the wireless access industry. The US has adopted no standard for advanced CT technology. Still, to maximize both the functionality and capacity of planned wireless access systems, US cellular carriers are considering CT technology for near-base-station communications. GTE's proposed TELEGO wireless network system is one early example. TELEGO is touted as a fully functional portable phone service which switches to fixed location CT mode when in the home base station area and switches back to "on the move" mode when outside the home base area and to mobile roaming mode when driving a vehicle far from the home base area.

The question of whether or not there is a market for CT type networks depends on the nature of demand. In particular, is the mass market characterized by a very dense and not very mobile population, both in terms of the speed of movement (slow) and the proximity of subscribers (close) to the base station? If the majority of the urban population tend to congregate in very limited areas (e.g., downtown rail/subway stations) and are not very mobile (usually on foot or on a bicycle), then CT networks may be the best market alternative among wireless access systems. Many Asian countries (among others) meet these criteria and they are likely to be early adopters of this technology.

Even in the US, there are potential mass market applications for advanced forms of CT technology, especially those which may become a good substitute for digital wired phone service, even in rural areas. For example, a standard has been specified for a *personal access communications system* (PACS) suitable for PCS and fixed wireless loop applications.[38] WACS employs a very low power microcell TDMA technology featuring a relatively low cost infrastructure capable of providing high quality digital service. However, no vendor in the US is actively pursuing deployment of such a system because the FCC has not licensed suitable spectrum for this purpose. Even with sufficient spectrum, in order for CT systems to be financially viable in rural applications high power levels would be required thereby increasing the coverage area of a single antennae site. The FCCÕs power restrictions associated with spectrum licenses (to avoid interference), often designed with dense urban areas in mind, becomes a limiting factor for the market viability of rural CT systems.

The network cost of CT technology deployment can range from nearly zero, in the case of the vastly popular household units, to very expensive, depending on the sophistication of the technology, power level, distance capability, functionality of the handset (e.g., paging, intercom), and the number and spatial distribution of base station locations and remote nodes. Advancements in the technology include increasing the practical operating distance between the base station unit and handset and increasing the number and locations of base station units and remote electronics (e.g., signal repeaters and amplifiers, and trunks). The CT mode of operation is relatively cheap to provide compared to mobile radio service and is almost strictly a function of the number of base station units, sub-units and electronics. The handsets are small and relatively inexpensive because they may operate on very low power. Capital costs associated with a CT network for trunking and interconnection are minimized because the phones only work near a base station and because relatively unsophisticated "plug in" connections to the PSTN may be used. As in any other portable communications network system, there are the usual operating costs including marketing, sales, network operations, administration, billing, etc.

Cell sizes for CT technology are very small (e.g., 100-500 meters radius). There are many versions of CT technology. The first generation Cordless Telephones (CT1) were simple single base station phones on a single fixed radio frequency connected to the PSTN. Beginning in 1985, the *Conference of European Posts and Telecommunications* (CEPT) initiated a standard for second generation cordless digital systems called Cordless Telephone 2 service (CT2--also called Telepoint). This is the first cordless technology to use digital voice coding (FDMA) and multiple base stations in a limited coverage area. CT2 functions like a normal cordless phone in non-Telepoint mode. When away from the home base, CT2 allows for only originating calls. CT2+, a second generation standard, allows for slow hand-off between cells. Telepoint was introduced in the U.K. with much fanfare in 1988 and dubbed Òthe poor manÕs mobile phoneÓ. By now, most CT2 service providers have given up and are being displaced in favor of newer digital cellular systems.

Also in 1988, CEPT decided on a new cordless system operating at a different frequency. Introduced in 1992, the new system was called *digital european cordless telephone* (DECT--European standard) and CT3 (Ericsson), a third generation CT technology which employs TDMA GSM techniques allowing for send and receive capability and adaptive channel allocation. Compared to CT2 phones, DECT doubled the transmission range (up to 300m outdoors) and permitted handoff between base stations. DECT, like CT2, uses 32 kb/s voice channels, but DECT may allow for combining channels for high speed data services. While DECT does allow for hand off and complete coverage in the area where the system is located, its geographical coverage area is usually restricted to a campus environment. The system design makes it an expensive proposition to cover a very wide area and still allow for roaming. The very popular worldwide standard for TDMA cellular networks, GSM, is basically the same as the European CT standard, DECT. The DECT standard defines compliant protocols for interworking with both ISDN and GSM.[39] Such compatibility promotes the deployment of the technologies as they may grow in tandem due to network compatibility and interconnection.

Early applications of public CT network technology were championed in the UK. Mercury has already launched the first PCN system (dubbed One-2-One) which now competes in certain market segments with macrocell mobile carriers. The consumer markets served by these two types of network access systems may not overlap as much as one might think. So far, the demand for the CT alternative in the UK has not substantially slowed the demand growth in cellular systems. In just two years, Mercury has signed up over 300,000 subscribers, two-thirds of whom never used a cellphone.[40]

In Japan, DDI has introduced the *personal handy phone* (PHP) which, due to widespread deployment of base station units, will feature wide area coverage and two-way capability, but will not allow for mobile communications due to lack of fast hand-off capability.[41] In Canada, the government has adopted a CT2+ technology standard, allocated spectrum and licensed several CT networks (e.g., Popfone, Telezone, Personacom).

4.7.2 SMR

SMR systems are the only wireless access technology being considered for the NII which is based on the traditional (non-cellular) model of two-way mobile radio. SMR systems use RF frequencies located adjacent to mobile cellular service frequencies, but when the FCC allocated them, they were single (paired) channel frequencies intended for high power, single antenna, large coverage areas for two-way radio and dispatch type services.

Beginning in 1987, Fleetcall (now Nextel) and others began purchasing and aggregating thousands of SMR frequencies in cities throughout America to achieve scale economies. With the help of FCC rulings allowing for different radio system configurations, Nextel was authorized in 1991 to construct digital radio networks using SMR frequencies. Today there are a handful of players that have pieced together coast-to-coast service capability.

With the assistance of *Motorola's integrated radio system* (MIRS) technology, the enhanced version of SMR (ESMR) relies on the same advances in digital signal processing that has opened up the future for all of the land-based wireless access companies. In ESMR systems, the old familiar scratchy and haphazard transmissions of taxi and emergency dispatch systems will be digitally enhanced to the point where they may compete with newer cellular systems.

ESMR systems using MIRS technology operate in a TDMA "cellular-like" environment. Such systems may expand the capacity of a single SMR radio channel six-fold allowing ESMR wireless access systems to have enough capacity to compete for the customers of cellular network systems. However, as is the case with current cellular networks, the capacity of ESMR systems for serving mass market demand may still become limited if PCS demand takes off.

The ESMR system cost per subscriber for wireless access is very difficult to estimate because some of the system infrastructure is already in place for existing lines of business, including dispatch and radio paging services. Suffice it to say that it is reasonable to assume that the per subscriber costs of upgrading SMR systems to ESMR using MIRS is lower than the system start-up and build-out costs of PCS competitors, and is probably less than digital cellular upgrade costs on shared AMPS/AMPS-D systems.

Because of the historical use of SMR radio frequencies for two-way radio dispatch and paging-type services and the installed base of subscribers to those services, ESMR wireless access system handsets will be among the first to offer multi-mode service. In fact, because ESMR systems will be built in market areas where a radio network infrastructure was already in place, they will be bringing the service to market potentially 2 to 5 years ahead of PCS systems, which cannot even begin the network build out until some time in 1996. This could represent a huge marketing and service advantage. However, as is often the case with being the first to trial a new technology, ESMR is having early service problems. As one ESMR business customer in Los Angeles put it, calls on the network "sound like you're underwater."[42]

4.7.3 Wireless cable systems (MMDS/LMDS)

Originally planned as a wireless broadcast alternative to cable television service, wireless cable systems are potentially capable of two-way digital access services in the NII. Originally, the FCC allocated spectrum (2.596-2.644 GHz) for the new wireless cable services. Thirteen video channels called *multipoint distribution service* (MDS) and *multichannel multipoint distribution service* (MMDS) were allocated for use by licensees. Additional spectrum (20 channels) using frequencies originally set aside for educational programming has been made available to MMDS operators so that a total of 33 channels could be offered. The FCC has since set aside certain RF spectrum for "response bands" for upstream signaling for interactive video services.

More recently the FCC has proposed allocating another 2 GHz in the 27.5-29.5 GHz band to a new service dubbed LMDS for uses similar to MMDS, but has not yet granted standard operating licenses. Recently, FCC has announced plans to allocate and auction more spectrum for this service in the 6 GHz band.

Both MMDS and LMDS systems plan to use digital technology to increase broadcast channel capacity and to provide for limited two-way interactive service. If the FCC allows it under its new flexible use policy, wireless cable systems could use two-way digital channels for telephony.

The basic cost structure of wireless cable technology is illustrated in figure 4.3. The systems will consist of a head end for combining video signals from terrestrial network and satellite feeds for transmission directly to subscribers. Subscribers to wireless cable systems receive the signals using a small antenna and signal downconverter and television set top box for channel selection.

Figure 4.3 Basic cost structure of wireless cable network.

The primary distinguishing characteristic of wireless cable systems' cost structure is their substantial up front fixed and getting started costs, and, in turn, the low incremental capital cost of adding subscribers. Most all of the incremental investment associated with subscriber additions is *customer premises equipment* (CPE), including the installation of the receiving antenna, signal downconverter, and television set top box. For this reason, such systems are especially well suited for high density urban applications. Due to line of sight requirements for clear television reception, wireless cable systems will have area coverage problems when adverse weather, terrain, and man made interference factors are present.

As with any video delivery system, wireless cable networks' use of digital technology is brand new. Significant advances in the network application of digital signal processing and compression techniques to support video on demand and interactive services are still largely on the drawing board. However it is a forgone conclusion that digital signal processing technology will be applied and that two-way capability will eventually be a reality. Since the original purpose of these wireless access systems was to provide for television service at fixed locations, the portability aspects associated with roaming have not been investigated. If roaming capability is ever to be in the cards for these systems, it will likely have to come from interconnection to other mobile systems which are interconnected to the PSTN.

While industry observers have mixed opinions regarding the ultimate capability of wireless cable systems to provide wireless access services as part of the NII, it is generally agreed that they will be a potentially significant player in the digital video business. Therefore wireless cable systems may be used by subscribers as a platform for broadband service in conjunction with other narrowband wireless access networks (e.g., PCS) to provide for a totally wireless mass market service platform in the NII.[43] Relative advantages of digital wireless cable systems include the rapid deployment feature of the technology and its ability to fill in the gaps for areas not otherwise served by wireline alternatives. Wireless cableÕs relative disadvantage is bad weather and terrain (especially trees), both of which can adversely affect the quality of the signal.

System upgrades and costs
Due to the very large coverage area from a single antenna site (e.g., 3,000+ sq. mi., 30 mi. radius) and the high subscriber densities offered by urban areas, the fixed network capital costs on a per subscriber basis for wireless cable (MMDS) systems are very competitive, lower than that for traditional wired cable systems. Average per subscriber system costs are about $500.[44] Variable cost for existing analog wireless cable systems are the dominant cost factor at about $350-$450 per subscriber, about half of which is CPE and half installation.[45] People's Choice TV in Tucson reports an incremental per subscriber system capital cost of $525 -- $380 of which is fully reusable if a subscriber discontinues service.[46]

On the near term horizon is the digitization of wireless cable signals which will allow for video compression and a dramatic increase in channel capacity (250 channels) and system functionality (e.g., video on demand, near video on demand). The system costs on a per subscriber basis will remain steady in a digital environment, although the cost of set top boxes will rise somewhat at first, but the increased system capacity will cause the per channel cost to fall dramatically. The price of digital signal converter boxes (by late 1996) is estimated to be about $300-350.[47]

Upgrading a wireless cable system which already has digital broadcast video capability to provide two-way digital wireless access service capability should not be too difficult, but very little hard data is available on the cost of doing so. One of the main reasons for this is that the FCC has not licensed the spectrum for telephony. Assuming that network operators are already planning to digitize their networks and use digital compression technology to expand channel capacity, the incremental fixed network costs to provide digital wireless access for two-way telephone services on a wireless cable system should be low. All that is required is that a portion of the broadcast radio links be assigned to upstream signal carriage. There may also be a network cost incurred to aggregate upstream traffic in a cellular-like or sectored environment similar to the way other narrowband wireless access systems plan to backhaul subscriber traffic. For example, wireless cable operators might employ remote antennae sites and signal repeater/amplifier stations for traffic aggregation allowing for shared use of upstream channels. In order to conserve broadcasting spectrum and make efficient use of that portion of the total available spectrum (about 200 MHz) band which must be dedicated to upstream communications channels, MMDS systems could employ the same shared access techniques used in PCS systems such as CDMA. Another possibility is the use of wireless LAN access techniques. As in all of the other wireless access systems, wireless cable systems could team up with local wireline network providers (telcos, cable television companies , etc.) for backhauling and terminating upstream traffic originating on the wireless system.

The variable per subscriber cost required to upgrade a wireless cable customer for two-way digital service however will not be nearly as low as the costs required for the network portion of the system, but, in any event, should not be any higher than that which a wired cableco would have to incur since both require sophisticated set top boxes to separate, combine, modulate and demodulate the incoming and outgoing signals. A set top "transverter" unit (a combination radio signal transceiver, codec, and up/down signal frequency converter) would be required to make the system work on a customer premises. Network equipment manufacturers have not yet announced the availability of digital equipment for wireless cable applications and therefore reliable cost data for upgrading the systems for digital wireless access service are not available.

LMDS systems differ from MMDS in network design and operation. Operating in a very high frequency band, the LMDS head end location will only be capable of serving a much smaller coverage area compared to MMDS due to the higher frequency signal propagation. Serving an entire city, metropolitan area, or remote locations, will require the system head end to feed signals to remote signal repeater/amplifier antennae sites designed for smaller coverage areas in a cellular design. To date, the FCC has issued only one license for LMDS service, to CellularVision, which operates a single experimental system in New York, but which plans to license its technology for many more systems throughout the US CellularVision's provisional license provides it with over 5 times the nominal spectrum available for use by an MMDS operator confusing sentence/clarify meaning. This obviously is an advantage as long as the costs required to cover an entire metropolitan area in a cellular arrangement are low enough to compete with single-tower two-way cable systems. The costs of these systems should still be lower than wired cable, since, like MMDS systems, the cost of laying cables and maintaining the wired system with all of its signal amplifiers is avoided.

LMDS cells sizes will vary, but may be as large as 12 miles radius (for very flat areas with no trees and dry climate) or as small as 1 mile radius or even less in areas with varied terrain like large urban centers. CellularVision claims its transmitter provides excellent service for a coverage area of 48 sq. mi. (4 mi. radius). Thus to serve a major city of say, 1000 to 2000 sq. mi., would require 20-40 transmitter sites.[48] LMDS technology has the capability and, if the FCC licenses it, the available spectrum, to provide two-way services including video telephony.

LMDS system capital costs per subscriber will be somewhat higher than for MMDS systems and will depend on the number of cells and remote transmitters required. In time, the costs of production CPE (e.g., antenna, downconverter, set top box) will likely be the same as for MMDS. The same is probably true for the cost of upgrading subscribers for two-way telephony using digital signal "transverters" located on the subscribers premises.

But for the greater spectrum bandwidth allocated to LMDS service, these systems face many of the same problems of MMDS operators in establishing two-way mobile and roaming services and would probably have to consider interconnection with another mobile system operator to become a full-service wireless communications company.

One example of a prototype LMDS video system using today's technology and subscriber equipment with cell sizes of 1-3 mi. radius (urban), estimates network system investment costs at about $40 per home passed, and for larger cells requiring repeater/amplifier nodes (e.g., 12 mi. radius suburban system) the cost is about $110 per home passed. On a per subscriber basis, the cost would be much higher depending on the penetration rate assumed. Associated CPE costs are estimated at about $700. Adding two-way narrowband telephone service adds substantially to these costs. The system capital costs per subscriber quadruples to about $200 and associated CPE costs are about $1,200. Both the network equipment and CPE costs should fall dramatically once manufacturers begin to provide production quantities. In a production mode, it has been estimated that equipment costs will fall such that a two-way LMDS system may be installed for about $700 per subscriber.

4.7.4 Satellite

Due to high up-front investment costs and the wide area coverage, the cost structure of satellite network systems is similar to that for wireless cable systems. The greater signal coverage area of the satellite system compared to land-based wireless systems make the potential per subscriber costs of satellite network systems very competitive. As with wireless cable systems, most of the variable cost per home passed or per subscriber will be for CPE. There are many types of new high powered, high frequency satellite networks and services on the horizon including LEOs, MEOs and GEOs. The FCC licenses providers of *mobile satellite systems* (MSS) operating in the 1.5-2.5 GHz band. Already the FCC has approved five licenses for so-called "Big LEO" systems.

The initial applications of the technology will be in niche markets for locator services, mobile roaming and remote telecommunications, where it eventually could dominate the scene. While it is technically possible that MSS networks may be used as a mass market substitute for fixed wired access, this seems very unlikely in developed countries with nearly universal access already available. While not a substitute for land-based wired networks, new digital satellite systems will potentially become important complements providing for worldwide connectivity. Many systems will offer dual-mode handsets capable of using either the satellite or interconnected land-based systems, whichever offers the most convenient or lower-priced service.

In addition to proposed digital satellite systems offering voice and data services, due to desirable cost characteristics it is anticipated that Direct Broadcast Satellite networks will be the dominant technology for distributing broadcast video signals worldwide for use by other land-based video distribution networks or directly to end users themselves, especially in remote locations or in locations not otherwise served by terrestrial networks. But this is not the only possibility. Assuming that the FCC continues to liberalize the uses to which spectrum may be put, DBS systems may be able to profitably expand into the two-way telephony business.

Table 4.4 provides a summary of proposed MSS systems.[49] From table 4.4 it is clear that major players are vying for a share of the MSS service market. Within the satellite services market, so-called small LEOs operating at lower frequencies will primarily serve niche markets for data and locator services (e.g., global positioning), while big LEO operators (e.g., Iridium, Globalstar, Teledesic) will target the market for worldwide two-way mobile voice and data services, including rural and remote locations and less developed countries.

Table 4.4
Proposed MSS systems

Organization	Investors	Cost to build	Service	Description
Iridium, Inc. Washington, D.C.	Includes Motorola, Sprint, STET, Bell Canada Enterprises and Daina Denden	$3.4 billion (include. launch)	1998	66 LEO satellites to link handheld wireless phones with global reach
Odyssey	TRW, Teleglobe	$2.5 billion	1998	12 MEO satellites